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16. Abstract The Starlette satellite is a passive device with no transmitting parts, designed to furnish geodesic information through laser firing from the ground. The design of the satellite and its flight specifications are described. Its mission will include study of geopotential, earth tides, oceanic tides, and polar movement, plus fine determination of the positions of the stations on the ground.					
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THE GEODESIC SATELLITE "STARLETTE"

Groupe de Recherches de Geodesie Spatiale

FIRST PART: SATELLITE

/2*

Geodesic Program: Starlette

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Introduction

The Starlette geodesic satellite is of extremely simple design: it consists of a uranium 238 ball covered with aluminum plates in which laser reflectors are embedded. The Starlette is a completely passive, nonstabilized system which in space serves as a target on which laser beams are reflected.

This surprisingly simple design for a space vehicle meets the need for efficiency in the geodesic mission the satellite is intended to perform. The purpose of this mission is to improve the geopotential model and to study deformations and movements of the earth (earth tides, oceanic tides, movement of the pole).

Such purposes require high precision in distance and time measurement, which may be obtained with the use of laser techniques. The influences of disturbances introduced by nongravitational forces (frictional forces, radiation pressure) which falsify the geodesic measurements should also be reduced to a minimum. These forces are exerted as pressure forces and are proportional to their surface area of application. The resultant accelerations are decreased as the weight is heavier for a negligible force, and thus for a small cross section of the satellite.

* Numbers in the margin indicate pagination in the foreign text.

In addition, in order to decrease these forces, the satellite should orbit at a sufficiently high altitude. This additionally offers an extremely long life for the satellite and thus the possibility of taking measurements over long periods of time.

Although the scientific mission of the Starlette program is /4 not innovative in nature, it nevertheless makes use of an original satellite totally adapted to the assigned objective.

There is reason to expect subsequent development of this type of satellite for the needs of geodesy. A virtual constellation of spheres with laser reflectors could be put into orbit during the next decade. At the same time, NASA is currently preparing a satellite, Lageos, which is identical to the Starlette, although with a much heavier weight, designed to orbit at a much higher altitude (6000 km).

I. Design of Satellite

The mission of the geodesic satellite Starlette is to study the shape and variable potential of the earth. To guarantee the success of this mission, the vehicle design should be perfectly adapted and should possess the following characteristics:

- a spherical shape permitting judicious distribution of the 60 laser reflectors over the surface of the satellite and making it possible to obtain echoes no matter what the position of the satellite in orbit may be;

- high density for a maximum decrease in the aerodynamic effects and radiation pressures exerted on the satellite;

- an extremely stable and known surface condition. All the tests which have been performed with the Starlette are based on calculation of gravitational forces. The problem is therefore

to isolate these forces on the basis of satisfactory knowledge of the other forces (pressure and radiation) to which the satellite is subjected; precise modeling of the surface forces will be performed. To this end, a ground experiment designed to determine the reflecting properties of the satellite will be implemented a few weeks prior to launching.

-- a magnitude of less than 13, that is, an adequate degree of brightness to permit photographs against a background of stars.

II. The Satellite

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The satellite is in the form of a metal sphere 240 mm in diameter, in which 60 laser reflectors are secured.

The functions of the structure are as follows:

- to support the laser reflectors;
- to provide the necessary weight;
- to offer known skin characteristics which are relatively stable over time.

This structure includes two parts:

- the core,
- the skin.

a) The Core

The core provides the weight of the satellite, resulting in the choice of an extremely dense material: tungsten or uranium.

The former material was not used due the machining problems it presents. Uranium 238, on the other hand, offers three attractive characteristics:

- ease of machining,
- density (18.7),
- moderate cost price.

Uranium 238 is a nonradioactive waste obtained from uranium 235, mixed with another substance, molybdenum, in a proportion of 1.5%. This extremely dense alloy is highly resistant to oxidation.

The uranium 238 block which constitutes the core of the satellite is cut in icosahedral shape (regular polyhedron with 20 triangular faces). This geometrical shape, offering 20 directions equally distributed in space, perfectly corresponds to the use requirements of the satellite. The weight is approximately 31 kg.

b) Skin

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The skin of the satellite, covering the core, consists of a compound alloy of aluminum and 5% magnesium. This alloy (AG5), which is more rigid than pure aluminum, holds up very well under machining.

Aluminum, in addition, is a stable and known material. Due to its stability it offers suitable resistance to different pressures and to the effects of radiation exerted on the satellite in orbit. It is also easy to evaluate any degradation undergone by the material or to control its development.

A spherical aluminum alloy plate with a triangular base is attached to each of the 20 faces of the icosahedron. Each plate supports three reflectors. The 20 directions of the icosahedron are thus split up into 60 emplacements in which the laser reflectors are arranged, permitting a relatively homogeneous spatial breakdown.

The skin was treated by micropeening in order to limit thermal differences which might result in deformation of the joints of the reflectors.

c) Laser Reflectors

The performances of the reflectors chosen are on the same order as those of the reflectors used in the D-1 satellite. The input face is circular rather than hexagonal. The reflectors offer advantages in regard to their attachment to the sphere and permit a regular skin surface. The number of reflectors was set at 60, making it possible to collect approximately 250 return photons for a satellite in orbit at 800 km.

Specifications of Satellite:

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Diameter:	240 mm
Radius:	120 mm
Weight of core:	31 kg
Weight of satellite:	47 kg
Density:	7

Nominal Orbit:

Perigee:	790 km
Apogee:	1050 km
Inclination relative to equator:	50°

III. Modeling of Surface Forces

Let us review the principal limitations caused by nongravitational forces, which may be characterized in the following manner:

-- the spectrum of these forces has a continuous component: the corresponding disturbances of the orbit may mask the phenomena one wishes to analyze, if these phenomena are at a fairly low level,

-- these forces possess periodic components which are difficult to distinguish from those being studied;

-- it is difficult to estimate these forces accurately: they may have irregular fluctuations, and are linked to parameters depending on the characteristics of the satellite (weight, shape, reflecting properties), it frequently being impossible to determine variations in these quantities over time.

At an altitude of 800 km -- corresponding to the perigee of the Starlette -- the disturbing acceleration due to atmospheric braking is $0.7 \cdot 10^{-9} \text{ m/sec}^{-2}$, while the acceleration due to direct solar pressure is $4 \cdot 10^{-9} \text{ m} \cdot \text{sec}^{-2}$ for a satellite of the Starlette type.

Due to the preponderance of radiation pressure, modeling ^{1/8} of this force should be performed with particular care, since in addition its frequency spectrum is identical to that of the phenomena which are to be studied.

To obtain better modeling of the solar pressure, it was decided to make experimental measurements of the reflection factors of the Starlette satellite prior to launching. Various types of methods were considered, and two were selected for use:

-- individual measurement of the scattered ρ and specular s reflection factors of the outer skin of the Starlette and of its laser reflectors, for different wavelengths. The overall reflection capability of this satellite was obtained by integration of the individual responses,

-- an optical method permitting overall energy detection.

An experiment conducted in a completely darkened laboratory consisted in illuminating the satellite by means of an artificial sun and measuring the energy transmitted by the satellite in all directions.

This method should make it possible to detect any anisotropy in the optical response of the Starlette due to the presence of the laser reflectors.

After integration of the angular distribution of the energy reflected, the measurements furnished an overall reflection factor k . It is not possible to obtain the individual parameters ρ and s by this method, but this does not constitute a limitation.

These two measurements were made in a parallel manner, and the aging of the skin of the satellite was measured at the same time.

IV. Compatibility with the Diamant BP4 Launcher

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1. Mechanical Connection

The satellite should be subjected to as little vibration as possible during launching. It is secured between two half-shells connected to each other by a band. The lower half-shell has three support points on which the sphere rests and an ejection piston equipped with a spring for separation. The upper part

includes an adjustable pressure prestress device (force exerted: approximately 1300 kg) which comes to rest against the satellite and prevents any movement of the sphere relative to its mounting.

At the moment of separation (pyrotechnical shearing) of bands), the prestress suddenly loosens, the upper half-shell quickly moves away, and the ejection piston releases and frees the satellite. This operation occurs approximately 20 min after takeoff.

2. Flight Sequence

The flight sequence is very simple, since it consists of only a single operation: separation. This procedure takes place at $H_0 + 1023$ sec. An order originating with the sequencer in the last stage commands the firing of two pyrotechnical shears which cut through two bolts and free the band.

The third stage is separated from the satellite by the same process described above. The separation velocity is 0.5 m/sec. This velocity is relatively low so that the satellite and the final stage will remain close to each other for a fairly long time to facilitate pinpointing of the satellite during its initial orbits. The third stage is equipped with a 136 MHz transmitter for this purpose.

The third stage-satellite assembly is spun at 130 rpm, under a retardation (yo-yo) system.

SECOND PART: SCIENTIFIC OBJECTIVES

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II. Scientific Mission of the Starlette Satellite

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Increasingly precise determination of the movement of a satellite in its orbit and of the positions of stations on the

ground, obtained through the development of new laser techniques, have made it possible to foresee the use of this trajectory to study certain parameters characteristic of the properties of the earth.

This includes:

- study of the earth's gravitational potential,
- study of the elasticity of the earth and oceanic tides,
- study of the movements of the pole,
- fine determination of the positions of stations.

Obviously it would be difficult to conduct these four missions simultaneously on a short-term basis. This would presuppose an extremely dense network of observation stations, especially for study of the movements of the pole and determination of the positions of the stations.

However, due to the long life of the Starlette, it should be possible to make frequent observations using devices with increased performance characteristics. It is thus possible to meet all the objectives of geodesy.

1. Study of Geopotential

The Groupe de Recherche de Géodésie Spatiale [Space Geodesy Research Group] (GRGS) is completing its research on the gravitational potential of the earth by determining a model of this potential, that is, calculation of the spherical harmonics of this field on the basis of satellite observations (basically, optical observations of direction and laser observations of distance).

The method used is based on an extremely high-precision /12
numerical integration of equations for the movement of a satellite
and equations furnishing the partial derivatives of measurements
in relation to the coefficients of the potential series. The
unknown parameters may be divided into two classes:

-- the spherical harmonics: up to degree and order 10
(approximately 120 coefficients) in an initial phase,

-- the coordinates of the 45 observation stations considered.

For the time being, the sum total of observations used is
divided into 26 "arcs" for the eight satellites D 1-C, D 1-D,
Peole, GEOS-A, GEOS-B, BE-B, BE-C, and Midas, each arc covering
12 to 19 days distributed over 1967 and 1971, and representing
approximately 40,000 equations for independent conditions ob-
tained in 3386 transits over the stations. For the laser
observations, these transits were made primarily during the Isagex
series.

Less ambitious, so far, than the other models of the Goddard
Space Flight Center (GSFC) and the Smithsonian Astrophysical
Observatory (SAO), these projects nevertheless had the following
purposes:

-- to acquire the experience necessary to extend these
methods to determination of the gravitational fields of other
planets and natural satellites (first, the moon, for which the
GRGS has requested batches of Doppler measurements from the
Apollo 14 and 15 missions, and then Venus, in connection with
proposals for participation in the American Pioneer and Soviet
EOS Venus missions),

-- to find an initial solution which will be fairly homo-
geneous, since it will be based on a large number of extremely

precise laser distance measurements (principally those obtained in the Isagex series).

To this solution will then be added measurements which will /13 be performed on the Starlette and D-5B satellites and gravimetric data which have already made it possible for the above-mentioned American laboratories to increase the resolution of their models.

The inclination of the Starlette (50°) serves to complete a range of laser satellites which now include seven satellites with different inclinations:

EOS-A:	60°
GEOS-B:	105°
Beacon-B (BEB):	70°
Beacon-C (BEC):	40°
D-1C:	39° to 41°
D-1D:	40°
Peole:	15°

With the Starlette and, soon, the B-5B (Castor), GEOS-C and Thimation satellites, there will be eleven laser satellites. This should permit determination of geopotentials solely on the basis of laser measurements. Thus these new data will make it possible to complete our knowledge of the earth's surface gravitational potential.

2. Study of Earth Tides and Oceanic Tides

The study of earth and oceanic tides on the basis of disturbances of satellites permits a direct approach to phenomena on a global level. With regard to the solid earth, these data are located on three levels:

-- data on the elasticity parameters of the earth through Love numbers;

-- data on imperfections in elasticity, that is, on the dissipation of energy associated with excitation; this dissipation is manifested by a delay between the exciting phenomena (gravitational attraction of the moon and the sun) and the earth's response (deformation of the globe);

-- data on the core; the presence of a nonspherical liquid core creates resonance at diurnal frequencies which has the effect of increasing the amplitudes of certain diurnal tidal waves. /14

Undoubtedly, the last two aspects of this phenomenon are of greatest interest; the principal Love number (k_2) is generally well known from ground measurements and seismic measurements. Furthermore, this parameter does not seem to be very sensitive to variations in internal conditions.

The earth tide delay constitutes an essential given: aside from comprehending the mechanisms of dissipation, the problem is to determine what quantity of energy has been dissipated, especially in the oceans. This is an essential question in understanding variations in the earth-moon system.

In an analysis of the phase shift, terrestrial methods give relatively unsatisfactory results, and so far it has not been possible to improve these results with the use of satellites. Given the long life of the Starlette and the precision of the lasers, it is hoped that it will be possible to determine parameters which will make it possible to comprehend these phenomena.

As for the third aspect, this should make it possible to determine the resonance frequencies due to the liquid core and

to compare them with those predicted theoretically, the ultimate goal being to obtain data on the compression of the core. However, at present it does not appear possible to perform this type of analysis using satellite observations, since the disturbances occurring at frequencies at which the resonances are probably located are currently undetectable due to the degree of accuracy of the observations.

In addition to earth tides, oceanic tides also disturb satellite orbits, with an identical frequency spectrum. In general, little is known about oceanic tides, and direct ocean measurements of these phenomena have been too few and far between to provide a basis for models. Current knowledge of oceanic tides is basically at a theoretical level (obtained by solving mathematical models).

The method of determining the main parameters describing oceanic tides through an analysis of orbital disturbances is original, first due to its newness, and second, because of the data it supplies on a global level, which may be used as limits in the theoretical models. /15

An analysis of observations from the GEOS-B satellite recently conducted by the GRGS has made it possible to obtain a new determination of the Love number ($k_2 = 0.29$) and has permitted an initial determination of the main coefficients of the principal oceanic tides (M₂, semidiurnal tide of lunar origin). It was not possible to determine the phase shift angle (delay between excitation and deformation), since the precision of the observations used was inadequate.

The Starlette satellite will contribute to improved knowledge of these phenomena, first, due to improved precision of measurement, and second, by decreasing the disturbing effects of

nongravitational forces, while at the same time affording a new possibility: precise analysis of long temporal series, which will be indispensable for revealing tidal disturbances, whose principal effects occur over very long periods of time.

III. Laser Techniques: Current State and Future Development

The laser techniques used for precise distance measurements since 1964 have entered an operational phase, as witnessed by the Isagex experiment in which ten stations observed seven satellites equipped with reflectors over a period of more than 6 months.

The basic advantages of this technique are:

- high precision, which does not appear to be limited; /16
- on-board devices which are of moderate cost and are passive, resulting in extremely long life;
- simple data processing which may be performed in only slightly deferred time;
- adequate coverage (generalized daily firing limited only by meteorological conditions).

These are general principles, but the actual realization of extremely precise but highly reliable measurements is a problem of applied metrology necessitating permanent improvements in all subsystems to render them operational.

Current stations produce noise of between 0.50 and 1.20 m and their systematic error is of the same order of magnitude; in addition, estimating this error presents a difficult and classi-

cal problem in metrology when a measurement device appears which is more precise than any currently in existence.

There must be a number of different approaches. As an example, let us consider that used for the French stations:

-- a priori evaluation of the systematic and aleatory error for each subsystem;

-- evaluation of noise by adjustment of the orbit during one pass and comparison with the preceding evaluation;

-- evaluation of systematic error by comparison of measurements made on a terrestrial target by different methods: problems arise from the fact that it is difficult completely to recreate the conditions of firing onto the satellite (signal is attenuated by intercalating different optical densities in the instrument);

-- evaluation of differences in systematic error between stations located at a single position, firing on the same satellite; /17

-- tests of measurement of the respective distances between two stations located 150 km from each other and comparison with a recent measurement of this base by conventional methods.

Currently, the best stations have the following characteristics:

-- power:	1 Joule (jewel)
-- impulse width:	15 nanoseconds
-- detection:	PM + detection of level for determination of maximum

meter	1 nanosecond
-- fire	on the basis of predictions
-- range:	4000 km.

It may be expected that the precision will reach 15 to 20 cm over the next 3 years and probably will reach a level of a few centimeters in 1980.

The principal improvements involve:

- the power (5 to 6 J)
- the impulse width (2 to 3 nanoseconds, then 0.1) or the use of modulated lasers
- the timing (0.1 nanosecond)
- the methods of detection
- analysis of outgoing and incoming impulses
- improved knowledge of instrumental delays
- improvement of the tropospheric corrections.

Actual satellite testing necessitates targets which are as nearly perfect as possible. The Starlette appears to be an ideal target for testing new systems from the ground.

Two French laser stations will be used for the Starlette mission:

- the GRGS station installed in San Fernando (Spain)

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-- the Office National de Recherches Aérospatiales [National Office of Aerospace Research] (ONERA) station (blind firing, in the Canary Islands).

There have been a few changes in the GRGS station which increased its performances. It notably includes a turret connected to a computer which integrates the transit predictions. This automatic device will make it possible to perform the blind firing made necessary by the small magnitude of the satellite.

In this station, the work procedures lead to rigorous computation of the orbital parameters with maximum elimination of error by means of a time shift or a shift along the trajectory of the satellite, followed by resetting to the satellite. This station additionally includes:

-- a clock adjusted to nanoseconds; the impulse width has been decreased from 30 to 15 nsec;

-- a system making it possible to determine the shape of the return echo, and thus also providing a means of collecting maximum data from it;

-- a new photomultiplier which will increase the range of fire.

Due to these modifications, it will be possible to determine the output and input time of the impulse with greater accuracy and, as a result, to improve the precision from 1.50 m to some 30 centimeters.

These improvements have been made with an view toward second generation laser stations, whose accuracy will be on the order of 15 nsec. The two French stations will complement those of the

Smithsonian Astrophysical Observatory (SAO) network and those of the NASA Goddard Space Flight Center (GSFC) network.

THIRD PART: OPERATIONS AND PROCESSING OF DATA

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Operations and Processing of Data

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The small size of the satellite (magnitude 11 and 12) and the lack of transmission necessitate installation of a specific procedure for tracking operations. These operations consist of two distinct phases. In an initial phase, which should last approximately 1 month (acquisition phase), the goal is to collect a maximum amount of data to establish a correct estimate of the orbit of the satellite. Only when this first phase has been completed will the laser tracking experiments begin; this will be the second phase, termed the exploitation phase.

I. Acquisition Phase

The satellite and the third stage are injected into orbit at an altitude of 800 km, approximately 10 min after launching. The assembly is spun at 180 rpm and does not include a retardation (yoyo) system.

Seven minutes later, the satellite separates from the third stage, moving away from it at a velocity of 50 cm/sec.

The following means are used for trajectography during launching:

* At the Launch Center:

-- the radar systems of the Centre Spatial Guyanais [Guiana Space Center], which track the first two stages of the launcher;

-- the interferometry devices of the Diane station of the Space Center, which collect the signals transmitted by the frame supporting the satellite and the third stage transmitter;

* downstream from the Launch Center:

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-- the NASA station located at Las Palmas and possibly that of the Landes Test Center,

-- The CNES stations in the Canary Islands and in Toulouse,

-- the NASA station in Winkfield (England),

-- the Stradivarius radar systems of the STTA [Service Technique des Télécommunications de l'Air; Technical Air Telecommunications Service] in Rennes and possibly the Royal Air Force system in Malvern (England), if the transit of the third stage passes through its beam.

-- four orbits 0, 1 and 2 (up to $H + 4$ hours):

Doppler observations at the CNES stations

interferometric observations at Kourour, Ororal (Australia), Quito (equator) and Winkfield.

Once the parameters for a precise orbit of the third stage have been collected, optical observations on a star background will be performed with the network of Baker-Nunn cameras at the Smithsonian Astrophysical Observatory. These observations will be performed on the third stage in order to reset the transit predictions, and subsequently they will be performed on the satellite itself.

The cameras are at the following locations:

- Hawaii
- Ouagadougou (Upper Volta), put in operation by the GRGS
- San Fernando (Spain)
- Mount Hopkins (U.S.)
- Athens (Greece)
- Olifansfontein (South Africa)
- Addis Ababa (Ethiopia)
- Arequipa (Peru)
- Maini-Tal (India)
- Natal (Brazil)
- Tokyo (Japan)
- Woomera (Australia)

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The cameras of the U.S. Air Force may participate in this operation.

II. Exploitation Phase

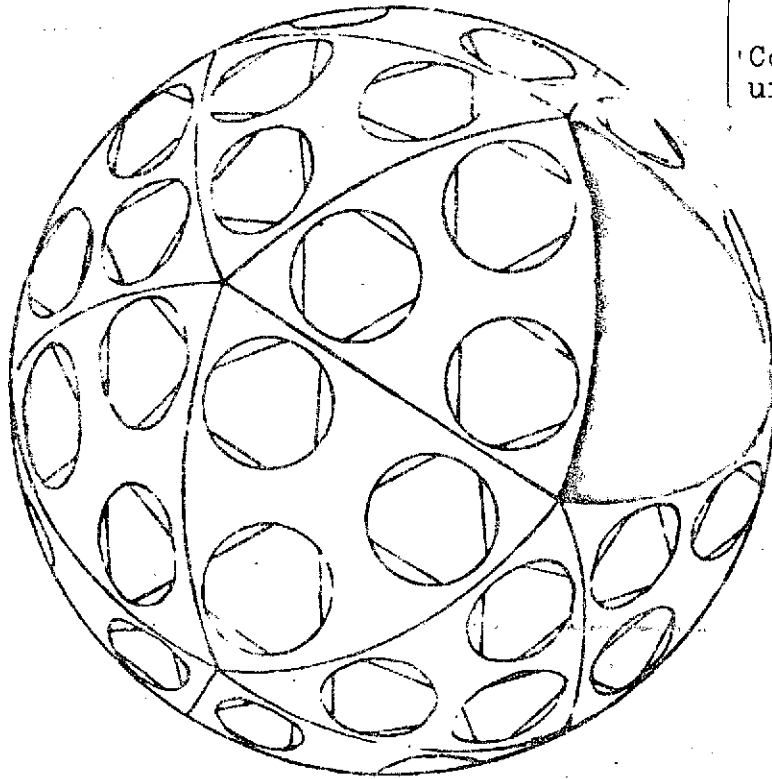
The exploitation phase can begin only when an adequate number of optical observations and laser echoes have been obtained.

During this phase, the optical observations and laser firings will be performed by the GRGS and the other organizations participating in the experiment, who will perform reduction of their own observations (decoding, calibration, synchronization, tropospheric corrections).

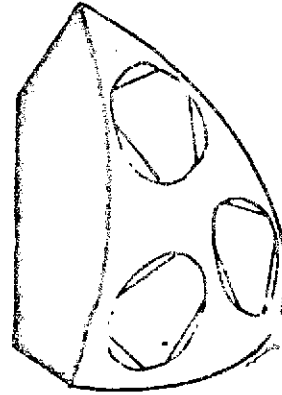
The Starlette satellite, a completely passive system, does not require specialized processing procedures. These procedures are limited to orbital computations which back up the operations of the tracking systems (cameras and lasers). Responsibility for the operations thus resides almost completely in

this tracking network, which, given the nature of the operations, is able to exploit the satellite directly.

✓ The Starlette is due to be launched from the Guiana Space Center on October 29, 1974, using the first Diamant-B-P4 launcher.



Core constructed of
uranium 238 alloy

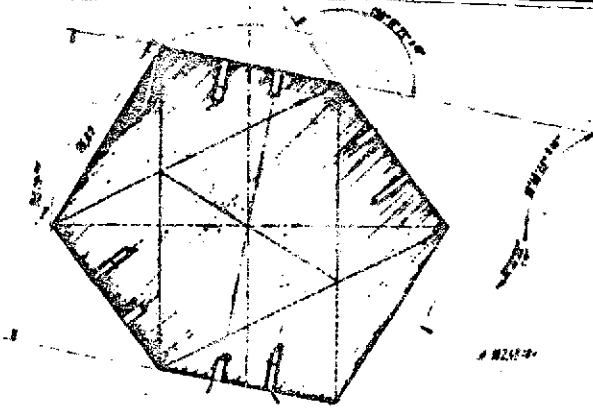


Aluminum alloy
plate

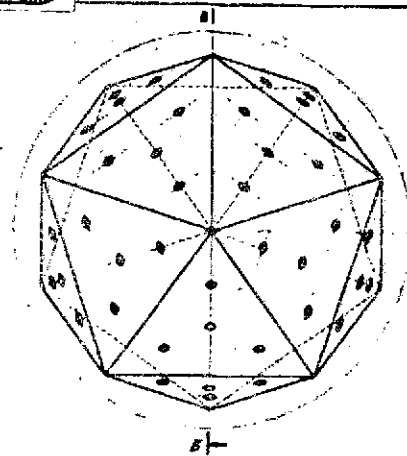
Number of reflectors: 60

Weight: 47 kg

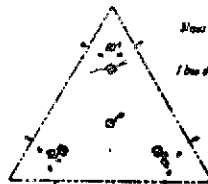
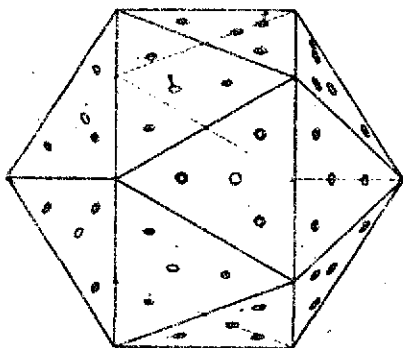
Diameter: 240 mm



10 faces 6 x 12
Profondeur totale 12 1/2"
Profondeur 8 1/2"
Cote: 10 x 12 1/2"
10 faces 6 x 12
Profondeur totale 12 1/2"
Profondeur 8 1/2"
Cote: 10 x 12 1/2"



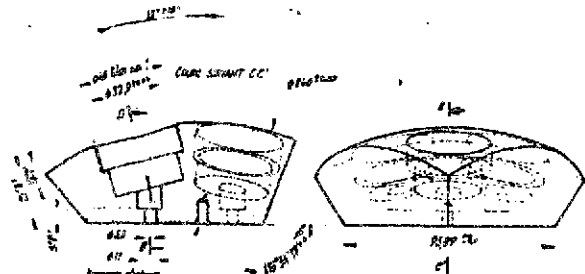
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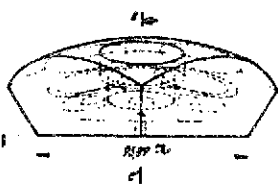
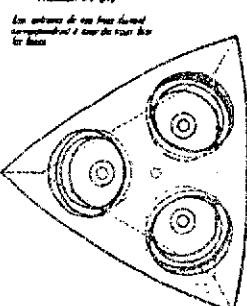
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Profondeur 8 1/2"
Cote: 10 x 12 1/2"

NOTES: Echelle 1/1
Mètre: 1/1
Cote: 1/1

REP 1



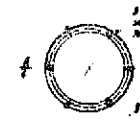
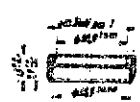
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10 faces 6 x 12
Profondeur totale 12 1/2"
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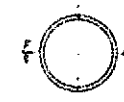
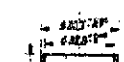


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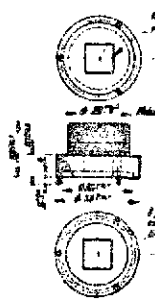
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REP 3



10 faces 6 x 12
Profondeur totale 12 1/2"
Profondeur 8 1/2"
Cote: 10 x 12 1/2"

REP 4



10 faces 6 x 12
Profondeur totale 12 1/2"
Profondeur 8 1/2"
Cote: 10 x 12 1/2"



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[All callouts
illegible]

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